SAR Evaluation Considerations for Laptop Computers with Antennas Built-in on Display Screens

December 2007
- Updated November 2009 -

Laboratory Division

Office of Engineering and Technology

Federal Communications Commission

Introduction

This document describes the procedures for determining SAR evaluation requirements of multiple antennas built-in around the edges of laptop computer display screens. Manufacturers and test labs may apply these procedures to reduce the number of SAR tests necessary to demonstrate compliance for certain transmitter and antenna configurations in typical full-size laptop and notebook computers.[1] The procedures focus mainly on 3G (WWAN), 802.11 a/b/g (WLAN) and Bluetooth transmitters where the higher output antennas are permanently integrated in the display screen.[2] Output power, operating characteristics and antenna configurations are considered in the procedures to minimize redundant and unnecessary SAR tests. The relative locations of antennas and their separation distances from users and nearby persons are used to determine the tests required to show compliance for both individual transmitters and simultaneously transmitting antennas.

Although the test requirements are based on frequency, power and distance, it should be noted that these simple laptop procedures may not apply to other products and exposure conditions. Other products and platforms may require in-depth considerations before frequency, power and distance can be related to energy absorption and SAR to streamline test requirements. The complexity of near-field exposure from simultaneous transmitting antennas and their contributions to the overall SAR in other product configurations, such as wireless handsets and laptop keyboards, are not been addressed in this document. Separate guidance for laptop/notebook/netbook and tablet computers with display screens smaller than 12" is available in a (November 2009) supplement to this KDB (616217). These supplemental procedures may be applied to the entire laptop/notebook/netbook and tablet computer, including the display and keyboard. The procedures in this document may continue to be used; however, these must not be mixed (used in conjunction) with the new supplemental procedures. Grantees and test laboratories are encouraged to use the new supplemental procedures to increase OEM integration flexibility and to minimize subsequent tests and Class II permissive changes.

SAR Evaluation Considerations

The operating and exposure characteristics of a transmitter can have substantial influences on SAR. The exposure potential of a device can usually be assessed through parameters such as frequency, power and distance to determine the tests needed for certification. A frequency dependent low power threshold of $60/f_{(GHz)}$ mW has been used for TCB approval purposes since 2002. Given that distance is not included in this formulation, it is unable to account for SAR changes due to different separation distances. It also cannot address the effects of external influences on SAR, such as wave propagation, energy coupling and (antenna and wave) impedance matching. The exposure conditions for products with multiple transmitters and simultaneous transmitting antennas are even more complex. Providing simple and flexible procedures to evaluate these highly complex exposure conditions can become quite difficult. Therefore, it is necessary to apply as many of these exposure parameters as possible to simplify the SAR evaluation and exclusion requirements for these exposure configurations.

[1] Displays 12" or larger are consider full size. The exposure conditions of tablet and laptop computers are different; therefore, laptop procedures are not applicable to tablets.

[2] The contribution of a very low power transmitter to the overall exposure potential of a laptop computer is generally insignificant; for example, a 5 mW or less Bluetooth device installed in the keyboard.

SAR is a measure of the rate of energy absorption inside tissues. It generally does not have a clear or direct relationship to the power transmitted by a source. SAR can be influenced by a multitude of exposure parameters and external factors between an antenna and the exposed tissues. Test results have shown that SAR varies with the operating and exposure conditions of a transmitter. The SAR of transmitters with identical output power can vary substantially due to differences in design and operating characteristics. Hence, simple power-based thresholds are no longer sufficient for estimating the exposure potential of devices that transmit simultaneously with multiple antennas.

Although SAR measurement standards have been available for several years, the procedures are intended for handsets only. They are not always suitable for evaluating the exposure configurations of other products. The lack of other measurement standards has left test labs with no options but to adapt these handset procedures for testing other products. Consequently, there is usually very little consideration of whether the procedures are indeed applicable. When the procedures are applied to devices with lower exposure potentials, such as antennas in laptop computer display screens, the test requirements can become excessive. To make matters worse, these single transmitter concepts are also applied inappropriately to multiple antenna configurations and significantly different exposure conditions where test integrity is often compromised.

While efforts are in progress to examine SAR and absorption based criteria to simplify test requirements, certain interim steps may be considered to reduce the number of tests required in situations where exposure potentials are relatively low. For antennas in laptop computer display screens, frequency, power and distance can be applied according to the operating configurations and exposure conditions of the transmitters and antennas to minimize the SAR tests. Laptop computers generally do not employ very high gain antennas. The output power for most transmitters employing digital modulations are generally rated according to average power. In order to maintain consistency and simplify the procedures, the thresholds considered in this document are based on conducted power according to source-based time-averaging requirements of §2.1093(d)(5). Until further considerations are available, these procedures should be limited to antennas with gain ≤ 6 dBi.

Individual Transmitters

Regardless of simultaneous transmission requirements, transmitters operating in laptop computers must be each assessed independently according to applicable rules and policies to determine RF exposure compliance. When the maximum transmitter and antenna output power are ≤ $60/f_{(GHz)}$ (mW) SAR evaluation is typically not required for FCC or TCB approval.[3] For antennas that are built-in within the display screen of laptop computers, a simple distance-dependent power threshold with respect to multiples of 60/f may be applied for output levels > 60/f to determine the number and types of tests required to show SAR compliance.

Power and distance are indirectly related to exposure potentials. Test requirements established according to these parameters are not SAR based. They generally do not account for the near-field energy coupling issues encounter at close proximity to antennas. Therefore, a minimum antenna-to-user separation distance of 5 cm is required by the procedures to avoid issues that can have substantial influences on

[3] See TCB Exclusion List for 60/f and low power threshold requirements.

SAR. Until SAR-based criteria are available to address these near-field conditions, the normal SAR test requirements should be applied to antennas located at < 5 cm from users and nearby persons.

When antennas are ≥ 5 cm from users, frequency, power and distance are applied to determine test requirements. If an antenna is ≥ (5 + ½·n) cm from users and nearby persons the number of tests can be reduced by evaluating SAR only on the highest output power channel. [4] The value of n is computed according to n = P/(60/f)-1; which is the number of times the antenna output power (P) is > 60/f. Both P and ½·n should be rounded respectively to the nearest mW and cm to determine the threshold distances.[5]

Simultaneous Transmission

When antennas transmit simultaneously at close proximity to each other, the SAR measurement considerations can become quite complex. Depending on the number of antennas, frequency, power and antenna locations, SAR distributions may overlap and vary substantially for different antenna and laptop computer configurations. The test requirements are expected to vary according to the operating configurations and exposure conditions of each laptop computer. It is necessary to characterize the exposure potential of each antenna and its influence to the other antennas base on frequency, power, antenna-to-antenna distances and antenna-to-user distances of all the antennas to establish test requirements.

The distance thresholds used for individual transmitters and antennas can be adapted to multiple antenna configurations to determine the number and types of tests required for simultaneous transmission. Besides antenna-to-user separation distance, a minimum antenna-to-antenna separation distance is also required to streamline test requirements. If the antennas are separated from each other with sufficient distances and the SAR distributions do not overlap, the 1-g SAR for simultaneous transmission is usually the same as the highest 1-g SAR among the individual antennas. However, depending on power and separation distance, when SAR distributions overlap it may be necessary to conduct simultaneous transmission measurements to assess the overlapping SAR contributions before the highest 1-g SAR can be determined.

The SAR distribution of antennas in small portable transmitters is typically around 3 - 5 cm wide. The effects of overlapping SAR distributions can be minimized if antennas are deployed at least 5 cm apart. For antennas that are closer than 5 cm from each other, certain higher output configurations may require simultaneous transmission evaluation to assess the overlapping SAR. On the other hand, if the antennas are separated sufficiently from each other and there is little or no SAR overlap, test reduction procedures may apply. Until SAR-based criteria are available, the 5 cm minimum antenna-to-user separation used in the standalone antenna test reduction procedures is also required for multiple antenna configurations.

When the output power of a simultaneous transmitting antenna is ≤ $60/f_{(GHz)}$ mW and it is either ≥ 5 cm from all other simultaneous transmitting antennas or it is deployed on the display screen at ≥ 5 cm from users and nearby persons, the contributions of such antennas to the overall exposure potential of the laptop

[4] Evaluate SAR on the highest output channel for the operating modes and antenna positions that require testing. See 3G and 802.11 a/b/g SAR procedures to establish the required transmitter operating conditions.

[5] The values of P and ½·n should be rounded to the nearest integer.

computer is generally small. [6] SAR evaluation for these types of simultaneous transmission configurations is unnecessary.[7] For simultaneous transmitting antennas with outputs > 60/f, the separation distances between these antennas are used to assess the overall exposure potential. The number and types of tests required for each simultaneous transmitting antenna to show compliance are based on the defined antenna configurations.

The number of times an antenna's output power (P) exceeds 60/f is defined by n = P/(60/f)-1, where n is a function of both frequency and power. This equation establishes the antenna-to-user distances required to reduce the number of tests for individual (independent, standalone) antennas. In multiple antenna configurations, each antenna has a different value of n. For example, $n_x = P_x/(60/f)–1$ defines the distance threshold for antenna (x) and $n_{yi} = P_{yi}/(60/f)–1$ defines the thresholds for antenna (y_i); where multiple antennas (y_i) may exist and contribute to the exposure of antenna (x). P_x and P_{yi} are the output power of the corresponding antennas rounded to the nearest mW. Each antenna is assessed once as antenna (x) and subsequently as antenna (y_i) while they are each considered as antenna (x). This process repeats for each simultaneous transmitting antenna and examines the exposure potential contributed by the antennas, according to their frequency, power, antenna-to-user and antenna-to-antenna relationships.

SAR evaluation is not required for antennas operating in mobile exposure conditions; therefore, these antennas are not assessed as antenna (x) for determining simultaneous transmission SAR requirements. For purposes of determining their exposure contributions to nearby antennas operating in portable exposure conditions, these mobile antennas should be included as (y_i) antennas to determine threshold distances for the portable antennas. Unless the output for one of the antennas is very high, it is unlikely that a mobile antenna at 20 cm with at least 5 cm separation from a portable antenna would require simultaneous transmission SAR evaluation. However, when tests are required for such conditions the FCC Laboratory should be contacted to determine the applicable measurement methods.

When a simultaneous transmitting antenna (x) is $\geq (5 + ½\cdot n_x)$ cm from users and nearby persons and it is also $\geq (5 + ½\cdot n_x + ½\cdot n_y)$ cm from another simultaneous transmitting antenna (y), the contribution of exposure from antenna (y) to antenna (x) is considered insignificant. [8] Antenna (y) does not need to be included in the simultaneous transmission considerations of antenna (x). In addition, if all other simultaneous transmitting antennas (y_i) are also $\geq (5 + ½\cdot n_x + ½\cdot n_{yi})$, the contributions of exposure from these other antennas (y_i) to antenna (x) are also insignificant. Hence, SAR evaluation for simultaneous transmission is not required for antenna (x). Minimum antenna-to-antenna and antenna-to-user separation distances of 5 cm are required for this test exclusion to apply. When both high and low output antennas are installed at different separation distances on a laptop display screen, the simultaneous transmission evaluation requirement is determined according to the antenna-to-antenna and antenna-to-user distance thresholds. Depending on output power and separation distances, antennas with lower outputs or larger separation distances may not require testing. Simultaneous transmission evaluation is required only for the antennas that do not satisfy the antenna $(5 + ½\cdot n_x + ½\cdot n_y)$ and user $(5 + ½\cdot n_x)$ separation distance thresholds. When the closest antenna-to-antenna distance is < 5 cm and the antenna is also closer than 5

[6] The separation distance is determined by the closest distance between the antennas or between an antenna and the user.
[7] When SAR evaluation for simultaneous transmission is not required for all the antennas installed in a laptop computer, the conditions described in II-e and II-h-2 of the TCB Exclusion List do not apply.
[8] The closest distance between the antennas or between an antenna and the user should be compared to the thresholds $(5 + ½\cdot n_x + ½\cdot n_y)$ and $(5 + ½\cdot n_x)$ respectively. The value of ½·n should be rounded to the nearest integer.

cm from users and nearby persons, SAR should be evaluated according to the normally required simultaneous transmission requirements for that antenna.[9]

Antennas deployed with low output power or increased separation distance generally have low SAR. When the sum of the independently evaluated (standalone mode) maximum 1-g SAR for all the simultaneously transmitting antennas is less than the SAR limit, SAR evaluation for simultaneous transmission is not required for all the antennas. This 1-g SAR summing procedure may be applied to all antennas installed in the display and keyboard of a laptop computer provided a minimum antenna-to-antenna separation distance of 5 cm is maintained for all the antennas. When the output of an antenna is > 60/f mW, that antenna is required to have a minimum antenna-to-user separation distance of 5 cm for the 1-g SAR summing procedure to apply.

Output power and separation distance considerations at several laptop computer transmitter frequencies are illustrated in Table 1. A summary of the SAR evaluation requirements for both individual and simultaneous transmission are shown in Table 2. A hypothetical step by step example of a laptop computer with several transmitters and antennas is included at the end of this document to illustrate the procedures. Although the procedures do not imposed limits on the number of simultaneous transmitting antennas, laptop computers typically incorporate 2 – 3 transmitters and 3 – 4 antennas. For most configurations once the basic information for frequency, power and distance are gathered it should be relatively easy to determine if test reduction and exclusion are applicable.

Different SAR measurement procedures are required to evaluate simultaneous transmission. When antennas transmit simultaneously in the same frequency band all antennas operating simultaneously in that frequency range should be evaluated within the same SAR measurement to determine the highest 1-g SAR. It requires a sufficiently large measurement region to enclose all the antennas. If antenna transmit-diversity applies to one or more of the antennas, each antenna may have to be evaluated separately according to the test software and SAR procedures required for antenna diversity. For antennas transmitting simultaneously in different frequency bands, different tissue simulating liquids and SAR probe calibrations are required for each measurement. The SAR must be evaluated separately for these antennas. When SAR has already been measured for the individual transmitters and antennas to demonstrate compliance, the results can be applied to reduce simultaneous transmission test requirements. This enables simultaneous transmission SAR to be tested using only the test configuration (RF channel, operating mode, antenna position etc.) that results in the highest SAR during individual transmitter (antenna) evaluation.

In order to combine the overlapping SAR distributions for antennas transmitting in different frequency bands, the laptop computer and relevant antennas must remain at the same test position for all measurements. This ensures the SAR measured at different frequencies can be summed correctly to compute the 1-g SAR. The same measurement volume must be used to enclose all the simultaneously transmitting antennas in each measurement. The same spatial resolution and grid spacing are also required in each measurement for the measured points to be summed on identically registered spatial grids to account for the overlapping contributions. Volume scans are required for simultaneous transmission measurements instead of the typical area and zoom scans. Each volume scan is equivalent to an oversized

[9] When the output of a simultaneous transmitting antenna is ≤ 60/f mW, either an antenna-to-antenna separation ≥ 5 cm or an antenna-to-user separation ≥ 5 cm is required for test exclusion to apply.

zoom scan. Because of the substantially larger measurement volume and smaller grid resolution required for this type of scans, the measurements are typically quite time consuming. While these measurement are complex and often have significant constrains, manufacturers can apply the procedures in this document to expedite equipment certification by determining before hand the specific conditions necessary to minimize or avoid such complex tests.

Other Considerations

Identical transmitter and antenna configurations deployed in the same display screen of different laptop computer models are covered under the same equipment certification. Additional approval is not required. When changes in material or construction are > 5 cm from any part of an antenna, new test data and permissive change filings are not required. If one or more antennas are shifted from their originally approved locations and the same or larger antenna-to-antenna and antenna-to-user separation distances are maintained, except when the previously measured SAR for either independent or simultaneous transmission is > 75% of the SAR limit and the new configurations also require testing, new test data and permissive change filings are also not required. When other test requirements and approval policies are applicable to an individual transmitter or antenna, they should be considered in conjunction with the laptop computer SAR procedures; for example, certain modular approval and unique antenna considerations relating to unlicensed transmitters and technology specific test requirements.

Table 1 – Example Output Power and Separation Distance Considerations

Output Power, P (mW)		(MHz)				
½·n		835	1900	2450	5200	5800
0		≤ 143	≤ 63	≤ 48	≤ 23	≤ 20
1		144	64	49	24	21
2	cm	288	127	98	47	42
3		432	190	147	70	63
4		575	253	196	93	83
5		719	316	245	116	104
n = P/(60/f)-1; P is rounded to the nearest mW and (½·n) is rounded to the nearest cm Antenna-to-antenna distance = (5 + ½·n_x + ½·n_y) cm. Antenna-to-user distance = (5 + ½·n) cm						

Table 2 – Summary of SAR Evaluation Requirements

Antenna Output Power (mW)	≤ 60/$f_{(GHz)}$	> 60/$f_{(GHz)}$
Individual Transmitter or Antenna	SAR not required	Antenna-to-user distance – ≥ (5 + ½·n) cm: test SAR on highest output channel only < (5 + ½·n) cm: test SAR according to normal procedures
Simultaneous Transmitting Antennas	SAR not required: antenna-to-antenna or antenna-to-person distance ≥ 5 cm	SAR not required: antenna-to-antenna ≥ (5 + ½·n_x + ½·n_y) and antenna-to-person ≥ (5 + ½·n_x) cm
	SAR not required: when ∑ (SAR_{1g}) < SAR limit, antenna-to-antenna distances > 5 cm and antenna-to-user distance > 5 cm if output > 60/f	
	otherwise, test antenna(s) using highest SAR configuration for the individual transmitter/antenna	

Example

The following is an example illustrating how the test reduction procedures are applied to a group of transmitters and antennas configured in a hypothetical laptop computer:

Assumed hypothetical configurations:

Transmitters and antennas

- 1900 MHz, 255 mW 3G transmitter with antenna located on the left edge of the display screen, at 10 cm from the bottom of the laptop base (with display open at 90º to the keyboard)
- 802.11 a/b/g transmitter with 50 mW output at 2.45 GHz and 25 mW at 5.8 GHz, using a single antenna for both frequency bands; located along the middle, top edge of the display screen
- 3 mW Bluetooth with an integral antenna built-in on the transmitter module, located on the keyboard section next to the left display screen hinge at 0.5 cm from the back of the computer

Closest antenna-to-antenna distances (according to configurations assumed above)

- 3G WWAN & 802.11 a/b/g: 23 cm (d_1)
- 3G WWAN & Bluetooth: 10 cm (d_2)
- 802.11 a/b/g & Bluetooth: 26 cm (d_3)

Antenna-to-user distances (according to configurations assumed above)

- 3G WWAN: 10 cm (r_1)
- 802.11 a/b/g: > 20 cm (r_2); SAR does not apply to mobile exposure conditions
- Bluetooth: 1.5 cm (r_3)

Antenna-to-user separation distance calculations for independent SAR requirements:

Output > 60/f: SAR evaluation is required when antenna-to-user distance is < (5 + ½·n) cm

- 3G WWAN: (5 + ½·n) = 5 + ½·[255/(60/1.9)-1] = 5 + 4 = 9 cm (R_1)
- 802.11 at 2.45 GHz: (5 + ½·n) = 5 + ½·[50/(60/2.45)-1] = 5 + 1 = 6 cm (R_2)
- 802.11 at 5.8 GHz: (5 + ½·n) = 5 + ½·[25/(60/5.8)-1] = 5 + 1 = 6 cm (R_3)
- r_1 (10 cm) > R_1 (9 cm); test reduction applies, SAR evaluation is required on the highest output channel only for the WWAN
- SAR does not apply to the 802.11 a/b/g antenna due to mobile exposure conditions; therefore, R_2 and R_3 do not apply

Output ≤ 60/f: user distance restriction does not apply; therefore, r_3 (1.5 cm) also does not apply and SAR evaluation is not required for the Bluetooth for independent transmission

Antenna-to-antenna separation distance calculations for simultaneous SAR requirements:

Output > 60/f: SAR evaluation is required when antenna-to-antenna distance is < (5 + ½·n_x + ½·n_y) cm

- 3G WWAN & 802.11 (2.45 GHz): (5 + ½·n_x + ½·n_y) = (5 + 4 + 1) cm = 10 cm (D_1)
- 3G WWAN & 802.11 (5.8 GHz): (5 + ½·n_x + ½·n_y) = (5 + 4 + 1) cm = 10 cm (D_1)
- 3G WWAN & Bluetooth: (5 + ½·n_x + ½·n_y) = (5 + 4 + 0) = 9 cm (D_2)
- 802.11 (2.45 GHz) & Bluetooth = (5 + ½·n_x + ½·n_y) = (5 + 1 + 0) = 6 cm (D_3)
- 802.11 (5.8 GHz) & Bluetooth = (5 + ½·n_x + ½·n_y) = (5 + 1 + 0) = 6 cm (D_3)
  - note: 802.11 is mobile and Bluetooth is < 60/f, calculation for D_3 is unnecessary
- d_1 (23 cm) > D_1 (10 cm) and d_2 (10 cm) > D_2 (9 cm), SAR evaluation for simultaneous transmission is not required for the WWAN antenna; it is also not required for the 802.11 and Bluetooth antennas

Output ≤ 60/f: SAR is not required when the antenna is ≥ 5 cm from other antennas or users and nearby persons

- Bluetooth: evaluation is required only if both antenna-to-antenna and antenna-to-user separation distances are < 5 cm
  - both d_2 (10 cm) and d_3 (26 cm) are > 5 cm, SAR for simultaneous transmission is not required; therefore, user separation distance (r_3 = 1.5 cm) does not apply

Change Notice:

616217 D01 SAR for Laptop with Screen Ant v01 changed to 616217 D01 SAR for Laptop with Screen Ant v01r01

Modified second paragraph of Introduction to identify the supplemental guidance for laptop/notebook/netbook and tablet computers for this KDB (616217).